PLATINUM
Canada

FOREWORD

Exploration for platinum group elements (PGEs) in Canada has accelerated in recent years, stimulated by higher prices and attractive geological potential. In view of the strategic importance of PGEs, combined with the current uncertainty about the reliability of supplies from the world's dominant producers, Canada offers a unique investment opportunity.

This booklet provides an overview of the platinum metals industry and is intended to support and encourage interest in PGE exploration and development in Canada. Our country has long been an important producer of byproduct PGEs but in light of encouraging exploration results, we could significantly increase PGE production in the next decade.

We examine the uses and markets for these metals, existing production, current exploration and the recovery of platinum group elements. Although not an exhaustive technical document, the booklet is intended to provide the nonspecialist in the financial, investment and corporate sectors with an overview of the platinum metals industry and the significant scope for development opportunities in Canada.

To promote PGE exploration and development in Canada, Energy, Mines and Resources Canada offers technical expertise through a wide range of publications and services. For further information please contact the Mineral Policy Sector, 580 Booth Street, Ottawa, Ontario K1A 0E4.

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CONTENTS

INTRODUCTION III

USES AND CONSUMPTION OF PLATINUM GROUP METALS 1

MARKETING AND PRICES 7
- Platinum 7
- Palladium 9
- Other Platinum Group Metals 10

MARKET OUTLOOK 11

WORLD SUPPLY OF PLATINUM GROUP METALS 13
- Primary Production 13
- Recycling 18

PLATINUM GROUP ELEMENTS (PGE) DEPOSITS 21
- Geological Description 21
- Canadian Developments 23
- Canadian Exploration 23

THE BENEFICIATION OF PGE-BEARING ORES 27
- Canada 27
- World 27

EXTRACTION AND REFINING OF PGEs FROM PRIMARY SOURCES 29
- Canada 29
- World 29

EXTRACTION AND REFINING OF PGEs FROM SECONDARY SOURCES 31

TABLES AND CHARTS

Table 1 - Platinum Consumption by Application, 1981 and 1987 2
Table 2 - Palladium Consumption by Application, 1981 and 1987 3
Table 3 - World Production of Platinum Group Metals, 1984-1987 14
Table 4 - Platinum Supply and Demand, Western World, 1981 and 1987 15
Table 5 - Palladium Supply and Demand, Western World, 1981 and 1987 16

Figure 1 - Precious Metal Prices, 1972-1988 8
Figure 2 - Selected Platinum Group Metal Occurrences in Canada 26

INTRODUCTION

The platinum group elements (PGEs) refer to six closely related metals: platinum (Pt), palladium (Pd), rhodium (Rh), ruthenium (Ru), iridium (Ir) and osmium (Os). These metals, among the scarcest of all metallic elements, commonly occur together in nature. The platinum group, particularly platinum metal itself, is widely used in decorative applications but the principal uses are industrial. Despite their relative scarcity and high price, unique physical and chemical properties have made PGEs indispensible in a variety of industrial uses.

The strategic importance of platinum metals to industry has caused concern during the past several years over political and labor problems in the Republic of South Africa, the largest supplier of PGEs to the western world. This concern fueled speculative activity in the marketplace and resulted in significantly higher prices. Despite the recent volatility of prices for the platinum metals, the long-term outlook is bright in view of forecast growth in industrial and decorative applications.

The search for economic PGE deposits is complicated by a diversity of occurrence types, the geology of which in many instances is not completely understood. Nevertheless, the future of the platinum metals industry in Canada appears promising. Given the geological diversification in Canada, the significant amount of ongoing PGE exploration, encouraging discoveries and the recognized technical capability of the Canadian exploration community, prospects for the identification of world-class PGE deposits in this country are considered to be good. Optimistic forecasts for future growth of PGE consumption, the possibility of supply disruptions, a stable political environment and a favorable investment climate in Canada are factors which will help this country to emerge as a major player in the international platinum metals industry during the next decade.

Catalytic converters use platinum group metals to reduce harmful automobile emissions (photo courtesy of Degussa Canada Ltd.).

USES AND CONSUMPTION OF PLATINUM GROUP METALS

Platinum group metals are used in a wide variety of applications in pure form and in a host of alloys combining different elements (PGEs) alone or with other metals. The diversity of uses reflects their varied and unique attributes, which may include chemical inertness and corrosion resistance, the ability to catalyze chemical reactions, high melting points, high strength at elevated temperatures, stable thermoelectric properties, good durability, low coefficient of thermal expansion, excellent reflectivity, stable electrical contact resistance and good high-temperature oxidation resistance.

Platinum and palladium are the most common PGEs found in nature. Platinum's principal uses are in catalysts designed to control automobile exhaust emissions and in jewelry. The main uses of palladium are in the electrical and electronics industries, and in dental alloys. Western world consumption of these two PGEs is shown for 1981 and 1987 in Tables 1 and 2.

Although the other PGEs are less important in absolute terms, rhodium, iridium and ruthenium are important to industry. For example, rhodium is used in automobile catalysts and as an alloying agent with platinum. Iridium is used in electrochemical and catalytic applications. The principal uses of ruthenium are electrochemical and electronic. Osmium is used in the chemical and medical fields.

One of the largest uses of PGEs is in the production of automobile catalysts. There are two distinct types of auto catalysts: an oxidation type that controls carbon monoxide and hydrocarbons, and the so-called three-way type that is designed to control emissions of carbon monoxide, hydrocarbons and nitrous oxides. Oxidation catalysts can contain either platinum or palladium, although most use a combination of the two metals. On the other hand, three-way catalysts require platinum and rhodium, although they normally also contain palladium. The use of oxidation catalysts has diminished as new environmental regulations governing nitrous oxides have come into effect. However, some automobile manufacturers use an oxidation catalyst in conjunction with a three-way catalyst. PGE catalytic units are currently the major technology being used to reduce hydrocarbon and nitrous oxide emissions in automotive exhaust gases, although research is continuing on alternative systems.

Table 1

PLATINUM CONSUMPTION BY APPLICATION, 1981 AND 1987

	1981	(000 grams)	1987
Western world			
Auto catalyst (net)	19 906		35 458
Chemical	7 776		6 065
Electrical	5 754		5 599
Glass	3 110		3 732
Investment	6 065		15 241
Jewelry	23 483		30 792
Petroleum Refining	4 354		1 711
Other	5 132		3 732
Total	**75 581**		**102 330**
Japan			
Auto catalyst (net)	5 910		9 176
Chemical	311		467
Electrical	467		1 400
Glass	1 555		1 400
Investment	6 065		10 420
Jewelry	19 440		27 993
Petroleum Refining	467		-
Other	1 555		467
Total	**35 769**		**51 321**
North America			
Auto catalyst (net)	13 374		18 351
Chemical	1 555		1 711
Electrical	2 177		2 022
Glass	622		778
Investment	-		2 644
Jewelry	467		467
Petroleum Refining	1 711		467
Other	1 866		1 555
Total	**21 772**		**27 993**
Rest of western world including Europe			
Auto catalyst (net)	622		7 931
Chemical	5 910		3 888
Electrical	3 110		2 177
Glass	933		1 555
Investment	-		2 177
Jewelry Refining	3 577		2 333
Petroleum	2 177		1 244
Other	1 711		1 711
Total	**18 040**		**23 017**

Source: Johnson Matthey Public Limited Company.

Note: Data converted from ounces; totals may not add due to rounding.

TABLE 2

PALLADIUM CONSUMPTION BY APPLICATION, 1981 AND 1987

	1981	1987
	(000 grams)	
Western world		
Auto catalysts	8 398	6 376
Dental	14 930	30 948
Electrical	24 883	50 232
Jewelry	6 532	5 132
Other	10 264	8 398
Total	**65 006**	**101 086**
Japan		
Auto catalysts	4 354	2 022
Dental	4 977	9 020
Electrical	11 197	28 771
Jewelry	1 866	2 488
Other	3 110	1 866
Total	**25 505**	**44 167**
North America		
Auto catalysts	4 043	3 732
Dental	6 532	13 374
Electrical	10 264	13 219
Jewelry	311	311
Other	4 354	3 577
Total	**25 505**	**34 214**
Rest of western world including Europe		
Auto catalysts	-	622
Dental	3 421	8 553
Electrical	3 421	8 242
Jewelry	4 354	2 333
Other	2 799	2 955
Total	**13 997**	**22 706**

Source: Johnson Matthey Public Limited Company.

Note: Data converted from ounces; totals may not add due to rounding.

Recently, Ford Motor Company of the United States reported that it had developed an alternative catalyst using unspecified material that is claimed to be as effective as platinum in meeting exhaust emissions.

The largest market for automotive catalysts is the United States, but the adoption of automobile emission standards across Europe will provide a great boost to platinum demand. Emission control regulations equivalent to 1983 U.S. standards have already been adopted by Austria, Sweden, Norway and Switzerland. Within the European Community (EC), standards are being phased in over several years, beginning in October 1988 for all newly designed car models with an engine displacement larger than 2.0 L. Standards for new model cars with engine sizes of between 1.4 L and 2.0 L are scheduled to take effect in 1991. Beginning in 1990, automobiles with engine displacements of less than 1.4 L will be required to meet minimum standards. More stringent standards for this group, equivalent to the 1.4 L to 2.0 L category, have been proposed although a firm timetable for implementation has yet to be agreed on. It should be noted that the adoption of the EC regulations is voluntary by member countries. Although all should eventually endorse the established standards, several countries have delayed or may delay implementation, including France, Italy and the United Kingdom.

Automobile manufacturers have the option of meeting EC emission requirements in the smaller engines by various means, including the so-called lean burn engine technology. However, to meet the more stringent standards, most likely will use some form of catalytic converter.

Even before the EC adopted the emission standards, demand for converter-equipped automobiles increased dramatically. In West Germany, more than 50 per cent of new cars sold in 1988 had these devices.

The beauty of platinum is captured in this broach and these earrings by Montreal jeweler Armand Brochard.

The use of PGEs in jewelry, the second largest use for platinum, is particularly large in Japan. This use of PGEs has also been growing in Europe, especially in the Federal Republic of Germany. Despite higher dollar prices, the demand for platinum jewelry in Japan remains strong because of the steady appreciation of the yen.

The petroleum refining industry uses PGEs, particularly platinum, as reforming agents to increase the octane rating of gasolines. This use has become more important in recent years as more stringent environmental regulations have restricted the amount of lead additives in gasoline. These additives are known to reduce the effectiveness of PGE auto catalysts. The refining industry also uses PGE catalysts in hydrocracking and isomerization.

One potential use, possibly a major new market for platinum, is in the manufacture of fuel cells. There are several promising applications for this technology, including stationary power generation systems. These systems offer significant advantages over traditional systems for potential energy efficiency and speed of construction. Another potentially important use is in transportation, particularly urban buses. Development work for stationary power generation systems is continuing.

In recent years the production of wafers, small bars, platinum coins and medallions has increased rapidly in response to growing investment demand. During 1988 three new platinum bullion coins were introduced: the Koala in Australia, the Maple Leaf in Canada and a 150 ruble coin in the Soviet Union. Beginning in 1987 the People's Republic of China issued a limited number of one-ounce platinum coins known as Panda. Before these new coins were launched the most important bullion coin was the one-ounce Noble from the Isle of Man, first introduced in 1983. Johnson Matthey Public Limited Company has reported in 1988 that the small investment products sector (products less than 10 oz), including coins, will increase 67 per cent over 1987, to approximately 11 000 kg.

In line with the Canadian government policy on apartheid, the Canadian Maple Leaf is being produced with metal from sources outside South Africa. The Royal Canadian Mint's first-year sales target for the platinum Maple Leaf was 3100 kg, the same as that projected for the Australian Koala.

The Royal Canadian Mint introduced a new platinum coin in 1988. Struck in 9995 fine platinum, the coins are available in four sizes (photo courtesy of the Royal Canadian Mint).

One of the largest markets for palladium is the electronics industry, where it is used to manufacture multilayer ceramic capacitors, thick-film hybrid integrated circuits, resistor networks and electrical contacts. The fastest growing market for palladium is in dentistry, where it is used in dental alloys and orthodontic and prothodontic devices. Much of this growth has resulted from the substitution of palladium for higher-priced gold.

MARKETING AND PRICES

The principal market mechanisms for the platinum group metals include long-term contracts between producers and consumers; physical metal markets in the major financial capitals such as New York, London and Zurich; and futures contracts on the New York Mercantile Exchange (NYMEX) and the Tokyo Commodity Exchange (TOCOM), as well as a platinum option which is traded through the International Options Clearing Corporation B.V. (IOCC) network.

Most PGE sales are transacted through long-term supply contracts between producers and major consumers or through professional metal dealers such as Johnson Matthey Public Limited Company, Engelhard Corporation, Degussa AG and J. Aron & Company. The importance of producer price lists as a reference for PGE transactions has greatly diminished in recent years, although Impala Platinum Holdings Ltd. of the Republic of South Africa still quotes a producer price. The largest South African producer, Rustenburg Platinum Holdings Limited, abandoned its price list in the early 1980s. During 1987 and 1988 the Impala producer price remained constant at $600* per ounce for platinum and $150 for palladium, despite the significant volatility of free market prices.

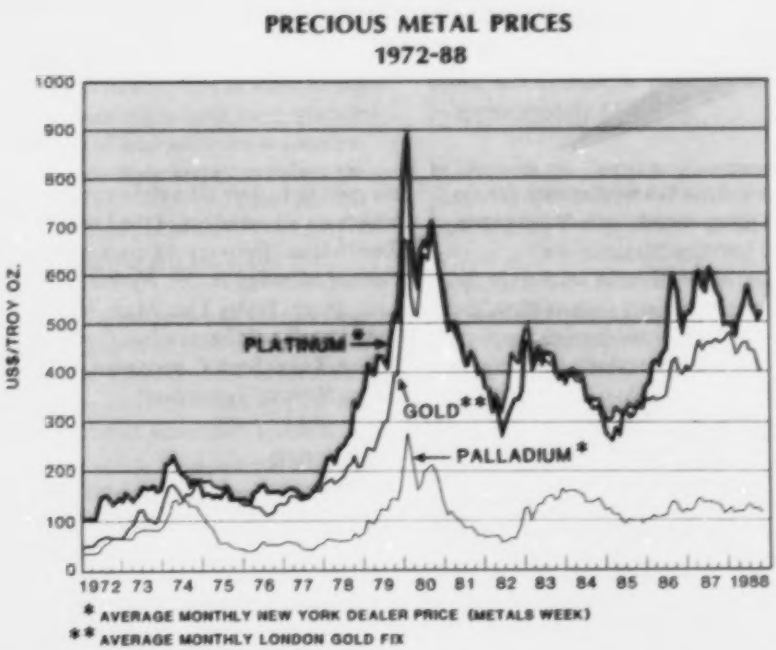
A new London terminal market (where metal is physically delivered) was formed during 1987. In 1988 it was reported that this market would be expanded to eight international firms and to two daily formal fixes, similar to those already in existence for gold and silver. The eight companies, which are all members of the London-Zurich Good Delivery Agreement, include Samuel Montagu & Co., Ayrton Metals Ltd., Sharps Pixley Ltd., Mase Westpac Ltd., Engelhard Corporation, Credit Suisse, Swiss Bank Corporation, and Union Bank of Switzerland.

Platinum

The platinum market has experienced two major periods of price escalation during the past decade (Figure 1). The first, which began in 1978 and peaked at more than $1000 per ounce in the first quarter of 1980, was the result of speculative forces caused by several economic and geopolitical developments. These included conflict in the Middle East, rapidly escalating energy prices and uncertainty caused by severe inflation, particularly in the United States. The second period of elevated prices, which began in the second half of 1985, has continued with some fluctuation through to 1988. The initial rise in 1985 was caused largely by a deterioration in the political and labor situation in the Republic of South Africa, which accounts for about 80 per cent of the western world supply of this metal. Platinum reached a recent high of $673.75 per ounce in September 1986, as concern over South Africa was exacerbated by fear that the South African government would restrict platinum exports in retaliation for economic sanctions imposed against its regime by some western nations.

** Prices in this publication are quoted in U.S. dollars. Ounce refers to troy ounce (31.103 g).*

Figure 1



During 1987 platinum prices, which averaged $518.86 per ounce in London during January, increased through the first part of the year. The increase was caused by the extreme weakness of the U.S. dollar, the threat of a renewed round of inflation and strong industrial demand. Platinum reached a high for the year of $646.50 on April 27. Prices softened somewhat in June, averaging $569, but they recovered in August and reached $633. This second peak was caused primarily by unrest in the Middle East and the threat of a mineworkers' strike in South Africa. The avoidance of any labor disruption at South African platinum mines, the threat of future oversupply and heightened fear of a recession after the stockmarket plunge in October caused generally lower platinum prices for the rest of 1987. The average price of platinum in December 1987 was $500.65.

Prices continued to soften at the beginning of 1988, reaching a low of $447.50 in February. Through March to June, prices climbed once again to reach $615.50 on the strength of buoyant demand in Japan combined with the growing likelihood of renewed inflation in the United States.

Beginning in July platinum prices began to ease - a trend that continued through August and September - dipping to less than $500. Toward the end of the year, it staged another recovery and prices rose to more than $600 in early December. Although this surge was attributed to strong demand, particularly in Japan, metal purchases for both the Canadian Maple Leaf and the Australian Koala coin programs were cited as contributing factors. Another reason was the growing likelihood of serious supply shortfalls. Johnson Matthey estimated that platinum

demand in 1988 would outstrip supply by more than 14 000 kg. With little new mine capacity expected before the early 1990s, this situation will likely continue for some time.

In response to the statement by the Ford Motor Company in mid December that it had developed a substitute for platinum in automobile catalysts, prices declined to $510 by year-end. However, with the surfacing of certain skepticism with regard to the Ford announcement, prices staged a slight recovery in January 1989.

Although concerns over possible supply disruptions from the Republic of South Africa - including possible economic sanctions and countersanctions - were overshadowed somewhat during 1988, these concerns continue to exert a significant influence on platinum metal markets. The importance of South African production to western world economies was dramatically illustrated in a 1988 report prepared by the U.S. Bureau of Mines. The report stated that an embargo on South African PGEs, particularly platinum and rhodium, would reduce the U.S. GNP by U.S. $12 billion per annum until at least 1992.

Platinum traded at a premium to gold through the late 1960s and much of the 1970s; the opposite was true for a large part of the early 1980s. Since the end of 1985 a premium over gold has been re-established. This premium to gold is believed to arise from the increasing critical industrial applications for platinum, the lack of competitively priced substitute materials and supply dependence on one major producing nation.

Given that the platinum market is approximately one-tenth the size of the gold market, it has been characterized by greater volatility. Since 1984 the volatility of platinum prices, measured by standard deviation over mean, has been almost twice that of gold.

Palladium

Movements in the price of palladium have largely mirrored those for platinum during the last decade. Like platinum, palladium prices rose in early 1980, exceeding $300 per ounce. However, palladium prices have not escalated as much as platinum prices since 1985.

Palladium prices in London, which averaged $123.41 in January1987, increased during the early part of the year to reach a 1987 high of $161 per ounce on April 27. Prices eased somewhat in June but recovered somewhat in early August to $147.75. Metal prices for the rest of 1987 were generally lower.

Palladium prices continued to fall in early 1988, to a low of $115.75 in February. They recovered after that, reaching $133.00 in June. Prices softened somewhat for the rest of the summer to less than $120 in September. As in the case of platinum, palladium strengthened once again in the fourth quarter of 1988. However, unlike platinum prices, which reacted unfavorably to the Ford Motor announcement, palladium prices reached a high for the year of $146 per ounce on the basis of speculation that it was the substitute in question.

Palladium failed to keep pace with platinum in recent years primarily because approximately 85 per cent of western world platinum supply comes from South Africa, but 53 per cent of palladium comes from the U.S.S.R. Political concern has been expressed over this reliance on the Soviet Union, but this appears not to have influenced the market. Palladium is also

not viewed as an investment commodity to the same extent as platinum or gold.

Other Platinum Group Metals

Relatively small amounts of the lesser known PGEs - rhodium, ruthenium, iridium and osmium - are produced. Collectively, this group constitutes about 15 per cent of South African PGE production and about 10 per cent of Canadian output. They are often characterized by thin trading and exaggerated price movements.

Speculative demand for rhodium, which is principally used in automobile catalysts to control nitrous oxide emissions, has remained quite strong during the past several years, in anticipation of the introduction of emission regulations within the EC. This strength is also attributable to the fact that the ratio of platinum to rhodium in three-way automobile catalysts may be as high as 5 : 1, compared with a Merensky ore ratio in South Africa of 20 : 1. Unlike platinum and palladium, rhodium prices during 1987 improved and were significantly much less volatile.

During 1987 rhodium prices increased from about $1100 to $1250 per ounce. Prices during the first half of 1988 were relatively stable at between $1225 and $1250. In July rhodium prices fell to about $1150 per ounce but recovered to their former level in the second half of the year.

There was some erosion of prices of ruthenium, iridium and osmium in 1987 and 1988. Ruthenium prices, which began in 1987 at between $75 and $80 per ounce, decreased to a range of between $67 and $71 by year-end, while iridium prices went from about $400 to $340. Prices for osmium, the rarest member of the PGM group, slipped from a trading range of between $650 to $750 per ounce at the beginning of 1987 to between $590 and $650 per ounce at year-end.

During 1988 ruthenium prices continued to soften. In November price quotations were between $60 and $64 per ounce. Similarly, iridium prices eased during 1988 to a range of $285 to $305 per ounce, while osmium prices fell to a range of $580 to $625 per ounce.

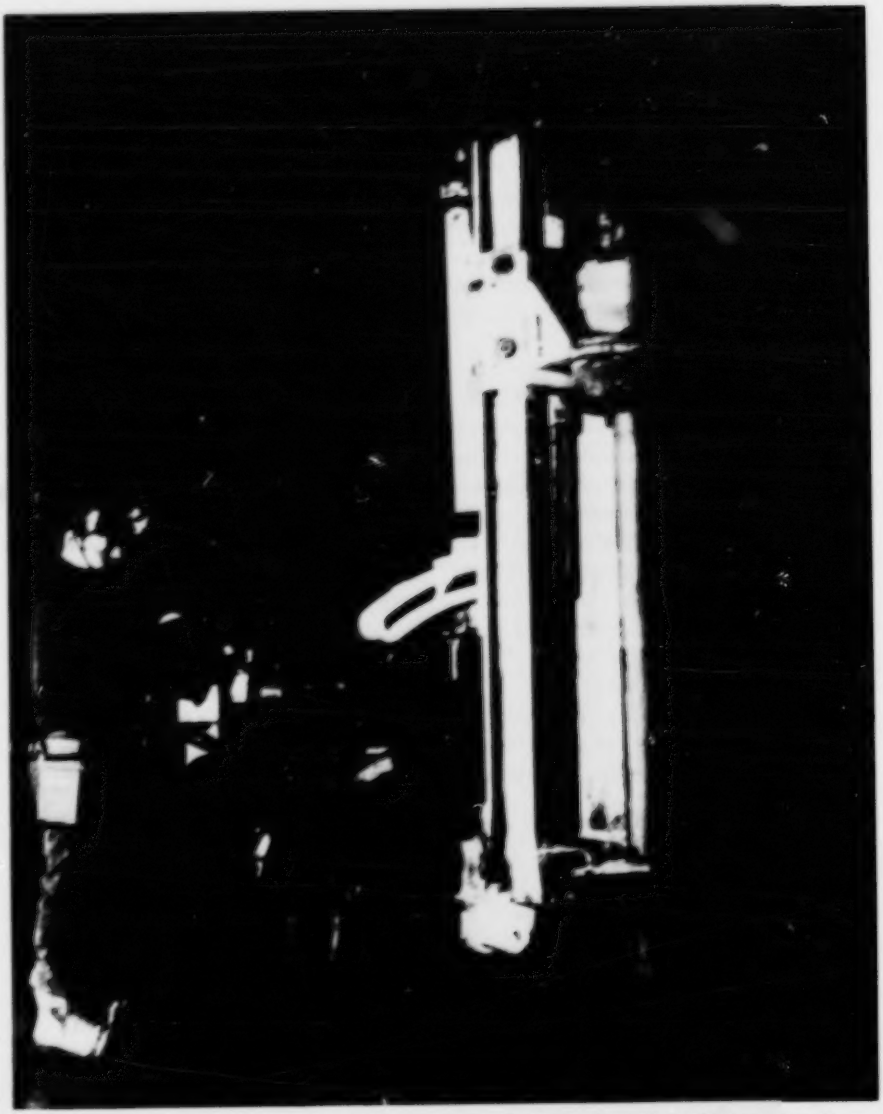
MARKET OUTLOOK

Notwithstanding some increases in PGE capacity, particularly in South Africa, the longer term outlook for platinum prices is positive in view of a 3.0 per cent to 3.5 per cent average annual rate of growth in demand predicted for the next decade. The major growth areas will continue to be the auto catalyst market, particularly in Europe, and jewelry. Demand from the investment sector is expected to increase, but this market will continue to be somewhat erratic. Development of effective alternatives to platinum in auto catalysts, however, could depress demand growth.

Demand for palladium in the important electronics sector, which increased significantly in 1987 and 1988, should continue to increase in 1989. A new palladium-based connector coating, which permits manufacturers to greatly reduce gold usage in electronic applications, has opened enormous new market opportunities for palladium. In addition, the large market for it in dentistry should continue to expand. Therefore, palladium demand is expected to match the 3.0 per cent to 3.5 per cent annual growth rate expected for platinum during the next decade.

New and stricter environmental controls on automobile emissions of nitrous oxides in the next decade will keep rhodium prices at or near recent highs, despite efforts to use rhodium more efficiently. Auto catalyst manufacturers are striving to increase the platinum : rhodium ratio in three-way catalysts from 5 : 1 to at least 10 : 1.

Despite short-term fluctuations in PGE markets, there is excellent potential for rapid growth in the industry. Optimism has already stimulated significant new investment in PGE exploration throughout the world and particularly in Canada. Given its geological potential, promising exploration results and geopolitical factors, the Canadian PGE industry will undoubtedly become an even more attractive focus for investment in the years to come.



Platinum group metals are contained in nickel-copper ores mined at Sudbury, Ont. (photo courtesy of INCO Limited).

WORLD SUPPLY OF PLATINUM GROUP METALS

Primary Production

World production of platinum group metals from 1984 to 1987 is shown in Table 3. The major world producers are the U.S.S.R., the Republic of South Africa, Canada and the United States. Others include Japan (from imported nickel and copper ores and intermediates), Colombia, the People's Republic of China, Finland, Australia, Yugoslavia and Zimbabwe. World primary production of PGEs was approximately 268 million grams in 1987, compared with 259 million grams in 1986.

The world supply-demand balance for platinum and palladium is shown in Tables 4 and 5.

Canada

Platinum group metals are recovered in Canada by INCO Limited and Falconbridge Limited as byproducts from the mining and processing of nickel-copper ores. Most Canadian PGEs are recovered from ores mined in the Sudbury basin, although small amounts are also produced in Manitoba: INCO's operations in Thompson, and the Namew Lake mine of Hudson Bay Mining and Smelting Co., Limited and Outokumpu Mines Ltd.

Canadian production of PGEs in 1988 was estimated at 11 500 kg, compared to 10 900 kg in 1987. Although a detailed breakdown of Canadian PGE production is not published for reasons of confidentiality, palladium output in recent years has been somewhat higher than that of platinum. Because of the size of its nickel mining operations, INCO is by far the largest Canadian PGE producer.

In addition to PGE recovery from nickel-copper operations, limited amounts are recovered from imported materials by the CCR Division of Noranda Minerals Inc. in Montreal, and the nickel refinery of Sherritt Gordon Mines Limited at Fort Saskatchewan, Alberta. Noranda also recovers PGEs from domestic and imported scrap. As with Canadian production by INCO and Falconbridge, this material is refined outside Canada.

U.S.S.R.

The U.S.S.R. derives PGEs principally as byproducts of nickel-copper production. For many years the U.S.S.R. has exported much of its PGE production to the western world and is currently the largest supplier of palladium to this market.

It is reported that 85 per cent to 90 per cent of Soviet production is produced from six mines in the Noril'sk region of northern Siberia. The U.S. Bureau of Mines estimates the PGE distribution of Noril'sk ores at 25 per cent platinum, 67 per cent palladium and 8 per cent iridium, rhodium, ruthenium and osmium combined. The average grade for PGE ores from Noril'sk is estimated at 9.6 g/t.

TABLE 3

WORLD PRODUCTION OF PLATINUM GROUP METALS, 1984-87

	1984	1985	1986	1987p
		(kilograms metal content)		
EUROPE				
Finland				
Palladium	34	35	96	90r
Platinum	33	35	120	120r
Yugoslaviae				
Palladium	96	103	96	96
Platinum	6	8	8	8
Subtotal	**169**	**181**	**320**	**314**
AFRICA				
Ethiopiae				
Placer platinum	4	5	5	5
South Africa				
Platinum-group metals	108 862	115 000	123 000	131 000
Zimbabwe				
Palladium	38	30	35	36
Platinum	24	19	26	26
Subtotal	**108 928**	**115 054**	**123 066**	**131 067**
ASIA				
Japan				
Palladium	1 051	1 359	1 453	1 417
Platinum	607	691	663	753
Subtotal	**1 658**	**2 050**	**2 116**	**2 170**
AMERICA				
Canada				
Platinum-group metals	10 369	10 534	12 190	10 930
Colombia				
Placer platinum	314	362	447	470
U.S.A.				
Placer platinum and platinum-group metals	455	w	w	w
Subtotal	**11 138**	**10 896**	**12 637**	**11 400**
AUSTRALIA				
Palladium	523	476	428	491
Platinum	66	95	115	131
Subtotal	**589**	**571**	**543**	**622**
EASTERN COUNTRIES				
U.S.S.R.e				
Placer platinum and platinum-group metals	115 000	118 000	120 000	121 000
WORLD TOTAL	**237 482**	**246 752**	**258 682**	**267 573**

Source: Energy, Mines and Resources Canada.
w withheld to avoid disclosing company proprietary data; excluded from "Total";
e estimate; r revised; p preliminary

The other principal source of PGEs in the U.S.S.R., accounting for about 10 per cent of Soviet production, is the Kola Peninsula, where these metals are a byproduct of nickel-copper mining. They are also recovered from placer deposits in the southern Urals, once the major source of U.S.S.R. output. Total Soviet reserves of PGEs are estimated at 6220 tonnes.

Republic of South Africa

There are three producers in the Republic of South Africa: Rustenburg Platinum Holdings Limited, Impala Platinum Holdings Ltd. and Western Platinum Limited. Unlike Canada and the U.S.S.R., South African PGEs are derived from ores mined primarily for their PGE content. South African ores also differ from Soviet ones in having a much higher ratio of platinum to palladium. The bulk of South African ores comes from the Merensky Reef of the Bushveld Igneous Complex in the Transvaal. These are reported to contain the following average grades: 3.24 g/t platinum, 1.37 g/t palladium and 0.7 g/t of other PGEs. Merensky ores also contain appreciable quantities of gold, nickel and copper.

Significant PGE reserves also exist in the UG-2 (Upper Group Chrome) and Platreef zones of the Bushveld Complex. Although deeper and somewhat more difficult to process, UG-2 ore accounts for an increasing share of South African production. This trend will likely continue as easily mined areas of the Merensky Reef are exhausted.

The UG-2 zone contains much more palladium and rhodium but less platinum than the Merensky reef. The breakdown of the average PGE values applicable to the

TABLE 4

PLATINUM SUPPLY AND DEMAND, WESTERN WORLD, 1981 AND 1987

	1981	(000 grams)	1987
Supply			
South Africa	55 986		78 381
Canada	4 043		4 354
Others	933		1 244
Sub-total	**60 963**		**83 979**
U.S.S.R. sales	11 508		12 441
Total	**72 471**		**96 421**
Demand			
Western Europe	13 063		17 418
Japan	35 769		51 321
North America	21 772		27 993
Rest of western world	4 977		5 599
Total	**75 581**		**102 330**
Western sales to Comecon/China	933		933
Movements in stocks	(4 043)		(6 843)
Total	**72 471**		**96 421**

Source: Johnson Matthey Public Limited Company.
Note: Data converted from ounces; totals may not add due to rounding.

TABLE 5

PALLADIUM SUPPLY AND DEMAND, WESTERN WORLD, 1981 AND 1987

	1981	1987
	(000 grams)	
Supply		
South Africa	28 304	33 903
Canada	4 977	5 910
Others	2 177	2 799
Sub-total	**35 458**	**42 612**
U.S.S.R. sales	44 478	55 675
Total	**79 936**	**98 287**
Demand		
Western Europe	9 331	17 262
Japan	25 505	44 167
North America	25 505	32 970
Rest of western world	4 666	5 443
Sub-total	**65 006**	**99 842**
Movements in stocks	14 930	(1 555)
Total	**79 936**	**98 287**

Source: Johnson Matthey Public Limited Company.
Note: Data converted from ounces; totals may not add due to rounding.

UG-2 zone is as follows: 2.46 g/t platinum, 2.04 g/t palladium, 0.72 g/t ruthenium, 0.54 g/t rhodium, and 0.21 g/t iridium and osmium.

South African reserves of PGEs calculated to a depth of 1200 m are estimated at 75 000 tonnes. However, a recent report by the Geological Survey of South Africa suggests that PGE reserves in that country may be somewhat larger, in view of recent evidence that the Bushveld Complex extends significantly beyond previously known boundaries.

Rustenburg, the largest South African producer, operates three mines in the Bushveld complex: Rustenburg, Union and Amandelbult. It also manages a fourth, Atok, for its affiliate Lobowa Platinum Mines Limited. Capacity of the Rustenburg operations, including Lobowa, is estimated at 65 300 kg of PGEs per annum. Rustenburg's existing expansion plans focused through or in partnership with Lobowa Platinum include a major expansion of the Atok mine, which could increase production from 1550 kg to 4350 kg by 1992. Another 5900 kg of output is expected from the first stage of the Maandagshock mine, expected to be on stream in 1991. If market conditions permit, another mine at Potgietersrus could also be developed in the 1990s.

Impala Platinum, South Africa's second largest PGE producer, operates a refinery at Springs and four adjacent mines, the Bafokeng North and South, and the Wildebeestfontein North and South. The company is thought to have an annual capacity of about 52 900 kg.

Impala, through its wholly owned subsidiary Gazelle Platinum Limited, is proceeding with the development of the Karee mine near Marikana. The site has about 130 Mt of Merensky ore reserves and 180 Mt of ore reserves on the UG-2 reef. The average grade from both zones is estimated at 5 g/t to 5.5 g/t. The company plans to bring the mine on stream in 1990-1991 at an output of 3100 kg per annum of platinum. This will eventually increase to 9300 kg per annum. At least part of the output from the Karee project will be used to offset the anticipated decline in output from Impala's existing operations.

Western Platinum Limited, owned by Lonrho S.A. Ltd., is the smallest South African producer. It operates one mine in the Marikana District of the Transvaal to the east of the Rustenburg operation. PGE capacity is estimated at 8500 kg per annum, although a current expansion will increase output to approximately 15 000 kg per year.

In addition to the expansions being undertaken by the three existing South African producers, as many as five additional mines may be developed in the medium term. Northam Platinum Limited, 72.6 per cent owned by Gold Fields of South Africa Ltd., is developing a new PGE mine southeast of the Amandelbult section of Rustenburg Platinum. Production is expected to begin in 1992, although the operation will not reach its full design capacity of up to 11 000 kg per annum until 1994. The prospect is reported to have reserves totaling 163 Mt grading 10.1 g/t combined PGEs plus gold.

Rand Mines Ltd., through its Barplats Investments Limited subsidiary, is proceeding with two new mine developments. The most advanced is the Lefkochrysos project, which Barplats gained control of in September 1988 from Golden Dumps (Proprietary) Limited. The mine, located near the town of Brits in the western Transvaal, is expected to begin production in 1989 and reach a planned first-phase output of about 8700 kg of PGE per annum by 1990. During initial production, mining activity will be restricted to the UG-2 zone. UG-2 ore reserves at the site are estimated at 125 Mt grading 5.9 g/t PGEs plus gold.

The second project is the Rhodium Reefs development in the eastern Transvaal. The project, which will initially exploit the UG-2 reef, is scheduled to commence production in 1991. Output from the mine is expected to be about 10 000 kg PGEs plus gold per annum during the initial production period; this will eventually increase to 15 500 kg per annum. Ore reserves at Rhodium Reefs are reported to be 84 Mt on the UG-2 grading 6.28 g/t PGEs plus gold. An additional 48 Mt grading 3.9 g/t is contained in Merensky Reef ores at the site.

Another new South African PGE mine development is Messina Ltd.'s project in the northeastern Transvaal. It is expected to come on stream in 1992 and reach a planned production capacity of approximately 8400 kg of PGE per annum by 1993. In 1988 it was reported that Impala Platinum was negotiating to purchase Messina from their mutual parent company Sanlam Investment Corporation Limited. Another possible PGE development is the proposed mine of Severin Mining Development in the eastern Transvaal. Although its ore grades are quite good, the Merensky and UG-2 reefs on this property are quite deep.

United States

The Stillwater Mining Company, jointly owned by Chevron Resources Company and Manville Corporation, is the only

primary PGE producer in the United States. The company's Stillwater Complex palladium-platinum mine in Montana began operations in March 1987. Production has steadily increased to an estimated annual rate of 3500 kg palladium and 1200 kg platinum at the end of 1988. With the development of a second mine at the site, the company expects to increase production by an additional 50 per cent by 1991.

The concentrate produced at Stillwater is processed by Métallurgie Hoboken-Overpelt SA in Belgium but the Stillwater partners are reported to be considering the construction of a smelter near the mine site.

Australia

The only PGE producer in Australia is Western Mining Corporation Limited, which recovers small quantities of palladium and platinum as byproducts from nickel mining operations. Because of the higher prices for platinum metals exploration in Australia, as in Canada, has intensified in recent years. Some of the more interesting areas include the Yilgarn, Pilbara and Halls Creek regions in Western Australia; the South Alligator Valley of the Northern Territory; the Broken Hill and Fifield areas of New South Wales; and Tasmania. One of the most promising projects is the Munni Munni deposit of Hunter Resources Ltd. in the Pilbara area. In this deposit, grades of up to 4.3 g/t PGEs plus gold have been reported. In the South Alligator Valley, the Coronation Hill gold-platinum deposit is being explored by BHP Gold Mines Ltd., Noranda Australia Ltd. and Electrolytic Zinc Co. From preliminary work, the companies have reported grades of 7.72 g/t gold and 1.76 g/t combined platinum and palladium. In the Fifield area - the site of limited PGE production at the turn of the century - Helix Resources has obtained values of up to 14 g/t platinum and 1 g/t palladium.

Other Countries

Elsewhere in Oceania, exploration for PGEs is taking place in New Zealand, Indonesia and Papua New Guinea. Attention is also being given to PGE occurrences in Brazil, Greenland, Zimbabwe, Ecuador and the Republic of Ireland.

Recycling

The recovery of PGEs from secondary sources, such as used industrial catalysts, electronic scrap and jewelry, is an important source of these metals in the western world. The U.S. Bureau of Mines estimates that recycling in the United States yielded approximately 42 000 kg in 1987, including some 7500 kg recycled on a non-toll basis.

Spent automobile catalysts are a growing and potentially important source of PGEs. With higher metal prices in recent years, competition in the scrap industry has intensified for used converters. Johnson Matthey estimated that scrap recovery of platinum from automobile catalysts in 1988 totaled 4700 kg.

Although the United States is the major source of PGE scrap from catalytic converters, between 65 per cent and 75 per cent is refined offshore, particularly in Japan. The major recycler of used auto catalysts in the United States is Texasgulf Inc.

During 1988 Platinum Lake Technology Inc. of Toronto announced the construction of a pilot-scale secondary recovery facility in Mississauga, Ontario. According to reports, the plant will use a new hydrometallurgical leaching process based on a proprietary chlorine-based

reagent (CRO/REDOX system). The Canada Centre for Mineral and Energy Technology (CANMET), of Energy, Mines and Resources Canada, has been involved with Platinum Lake in developing this technology. Although initial tests will concentrate on the recovery of PGEs from catalytic scrap, the process could be used to recover PGEs from primary sources.

Rock surface displays a typically layered intrusion that could host PGEs (photo courtesy of International Platinum Corporation).

PGE DEPOSITS

Geological Description

PGEs occur in several geological deposit types, nearly all in association with mafic and ultramafic igneous rocks (dark magnesium- and iron-rich rocks that originated deep in the earth's crust or in the underlying mantle). They have several forms:

1) chiefly as PGE minerals, but also in small quantities as a solid solution (in the crystal lattices) of some sulphides, arsenides and sulpharsenides associated with mafic or ultramafic rocks;

2) as PGE minerals associated with small amounts (1 per cent to 5 per cent) of nickel-copper-iron sulphides, some of which also contain PGEs in solid solution, concentrated in thin layers or zones within mafic and ultramafic rocks; and

3) as native PGE or PGE-iron alloys or other PGE minerals associated with chromite.

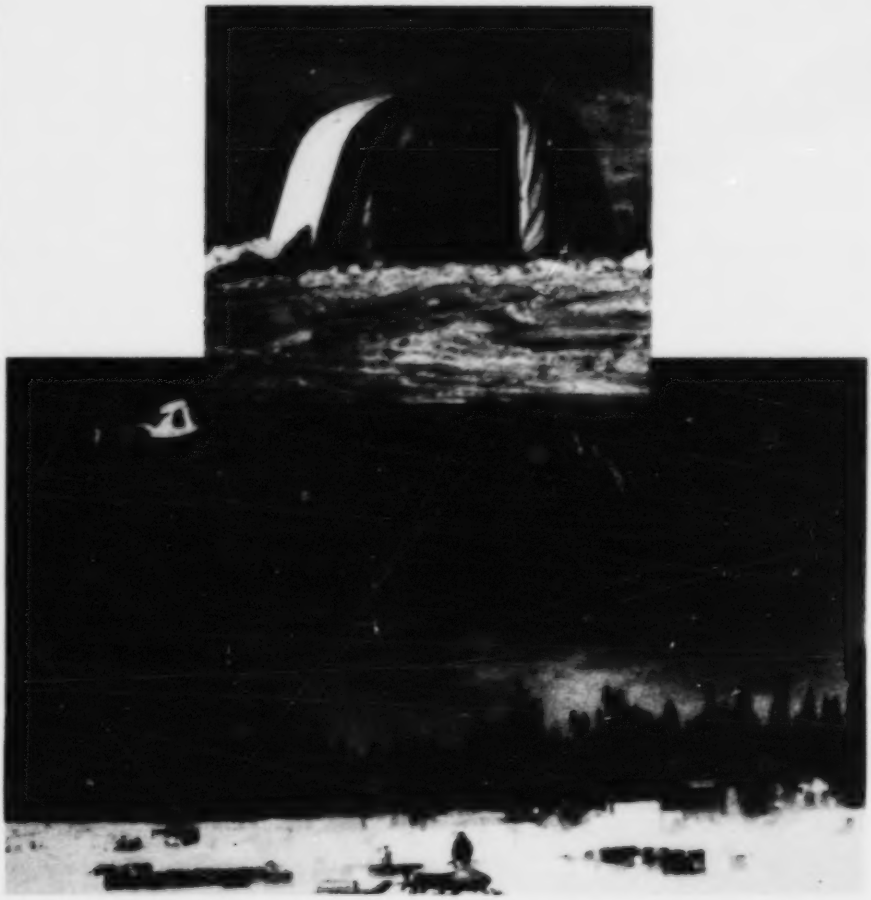
By far the world's largest known occurrence of PGEs is the Bushveld Igneous Complex in the Republic of South Africa, a layered saucer-shaped igneous intrusion that is 240 km by 420 km in area and 15 km thick. PGE deposits are found in the lower 7 km to 9 km of thick, complexly layered series of mafic and ultramafic rocks. At least four major and several smaller PGE zones of ore grade have so far been recognized in the Bushveld Complex, occurring in four or five different PGE deposit types.

The enormous size of the four largest known PGE zones in the Bushveld Complex is evident in that any one of them contains sufficient ore to supply 100 times the world's total PGE requirements for 1986. Other comparable zones may yet be discovered in the complex. In addition to PGE ore, the intrusion contains other separate orebodies of chromium, iron ore and the phosphate mineral apatite.

The best known deposit within the Bushveld Complex is the Merensky Reef, from which the bulk of South African production is derived. Canada has several deposits of this type; the best known and most promising is the Muskox intrusion in the Northwest Territories. Others possibly include the Big Trout Lake deposit in Ontario and the Fox River Sill in Manitoba.

A number of other deposit types in Canada hold considerable interest for platinum exploration or are already important as sources of these metals. PGEs are recovered as byproducts from the mining of massive nickel-copper-iron sulphides found associated with gabbroic rocks near the base of the Sudbury Igneous Complex. Orebodies average about 1 g/t PGEs (some higher grade deposits contain as much as 3 g/t), and have a platinum : palladium ratio of about 1 : 1. Recoverable reserves of PGEs in Sudbury district ores total about 370 000 kg. Additional reserves are almost certain to be found.

Another deposit type that could have significant PGE potential in Canada is the



Exploration sites at Big Trout Lake in northwestern Ontario and the Muskox intrusion in the Northwest Territories (photos courtesy of International Platinum Corporation).

Noril'sk type, named after the important copper-nickel-PGE deposits in the U.S.S.R. In this case, disseminated sulphide veins and massive copper-nickel deposits occur near the bases of layered gabbroic (mafic) to ultramafic intrusions that formed the feeders for volcanic flood basalts. The sulphide minerals apparently formed when the molten magma penetrated and ingested large amounts of gypsum and coal, which resulted in the formation of sulphide droplets that collected copper, nickel and PGEs from the magma and accumulated to form orebodies. To date, the most important Canadian deposit of this type is the Crystal Lake intrusion in Ontario.

An additional PGE deposit type in Canada is associated with nickel-copper deposits in Precambrian greenstone belts. These deposits consist of irregular lenses of iron-nickel-copper sulphides within the host igneous rocks, which are intruded into, and are of related origin to, sequences of green volcanic rocks. Within this broad deposit type are two subtypes, Pechanga and Kambalda (komatiite). The Kambalda

subtype includes the Thompson nickel belt, the Nar[illegible] Lake nickel deposit in Manitoba and the Dumont nickel deposit in Quebec. Several deposits in the Ungava area of Quebec display similar geology.

Another PGE deposit type with potential importance to Canada is the Alpine (ophiolite) type. Ophiolites are ultramafic rocks consisting of parts of the earth's oceanic crust and the underlying mantle that have been amalgamated (in the solid state) during mountain building. Some of these ophiolite complexes include relatively small deposits of chromite that contain up to 0.9 g/t of PGEs.

Zoned ultramafic intrusion-type PGE deposits in Canada are also of interest. Zoned ultramafic intrusions can contain crude concentric zones or shells of ultramafic to mafic rocks surrounding dunite cores. Dunite is a green ultramafic rock consisting of 90 per cent or so of the mineral olivine: $(Mg, Fe_2)SiO_4$. PGEs occur in the core zones with chromite. These zones are sulphide-poor and chromite-rich. They may contain economic amounts of the iron mineral magnetite. Most of the PGEs occur in the form of platinum-iron alloys and some as platiniridium. In Canada these PGE-bearing ultramafic intrusions were emplaced during mountain building and are referred to as Alaskan subtype. Several of them are in British Columbia. The Tulameen ultramafic intrusion is perhaps the best known.

Other promising occurrences in Canada are contained in miscellaneous deposit types. These include PGEs in certain deposits of hydrothermal origin, such as gold-bearing quartz veins, or in hydrothermally altered rocks. Some of the more interesting deposits of this type include Rathbun Lake, Ontario; Mother Lode, British Columbia; and the Beaverlodge area of northern Saskatchewan.

A unique deposit is near Marathon, Ontario, north of Lake Superior. It consists of disseminated iron-nickel-copper sulphides in a gabbroic part of the Coldwell complex composite intrusion. The intrusive rocks are alkalic, that is, they contain more sodium and potassium than is normal.

Canadian Developments

Although significant exploration is going on in Canada, Madeleine Mines Ltd. was the first company to announce a PGE development. The company's plans for its optioned Lac des Iles deposit include an open-pit mine with a mining rate of about 2700 tonnes per day. The projected yield from the operation is estimated at 2400 kg of PGEs per annum. The company has estimated mining and milling costs of $9.90/t of ore. Estimated reserves on the targeted Roby zone are more than 20 Mt grading 6.4 g/t PGE, with a reported platinum : palladium ratio of 1 : 7, plus 0.69 g/t gold and 0.25 per cent copper-nickel.

Although preliminary work at the mine site, including the erection of a concentrator, is at an advanced stage, a production decision has been delayed pending the conclusion of suitable arrangements for processing mill concentrate.

Canadian Exploration

There are many areas in Canada with significant PGE potential; some of the more promising are shown in Figure 2.

At least 13 copper-nickel deposits are known in the Labrador Trough area of Quebec. One of the major players, La Fosse Platinum Group Inc., has identified

Diamond drilling at the Lac des Iles project, northwestern Ontario (photo courtesy of Madeleine Mines Ltd.).

Removal of overburden at Lac des Iles platinum metals property in northwestern Ontario (photo courtesy of Madeleine Mines Ltd.).

several deposits in the Blue Lake area near Schefferville with significant PGE, nickel and copper values. During 1988 La Fosse reported additional discoveries at properties in the Gerido mining division. Designated as Chrysler North and South, PGE values of up to 7.55 g/t plus gold have been discovered.

In the Cape Smith Belt of the Ungava region of northern Quebec, extensive high-grade nickel-copper deposits with PGEs have been identified. Falconbridge Limited, Oasis Resources Inc. and Les Mines Messeguay Inc., have reported values on their Delta Sill project of up to 7.8 g/t PGE.

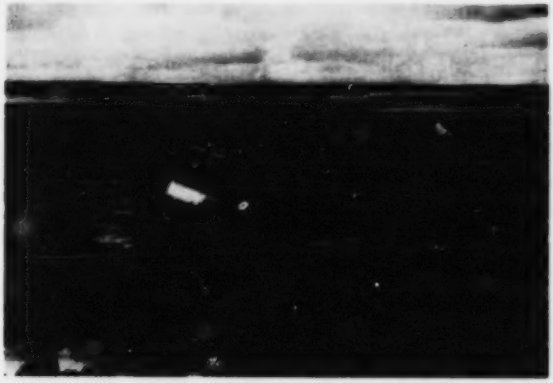
In addition to Madeleine Mines Ltd., other companies are involved in exploration at Lac des Iles in Ontario, including American Platinum Inc. and Heenan Senlac Resources Ltd. Further west, but still in the same belt of mafic to ultramafic intrusions, Fleck Resources Ltd. can earn a 50 per cent interest in the Bedivere Lake property of Coventry Ventures Inc. by spending $1 million by September 1994.

Still farther west, Fleck is involved in an exploration program on the Kawene joint venture with St. Joe Canada Inc.

Other promising targets in Ontario include the Marathon deposit of Fleck Resources Ltd. The deposit contains 9 Mt grading 1.87 g/t PGEs or 53 million tonnes grading 1.11 g/t PGEs with values as high as 24 g/t PGEs plus 1.6 g/t gold, 25 g/t silver, 2.4 per cent copper, 0.79 per cent nickel and 0.51 per cent cobalt. The property is under option to Euralba Mining Ltd., which can earn a 51 per cent interest by spending $2 million by May 31, 1989 and delivering a feasibility study. Also in Ontario, a property at Big Trout Lake is being explored by the PGM Syndicate, a joint venture involving International Platinum Corporation, Degussa AG and Jenkim Holdings (Canada) Limited. Preliminary test results at Big Trout Lake indicate PGE values of up to 9.6 g/t.

Mill construction at Lac des Iles platinum metals property (photo courtesy of Madeleine Mines Ltd.)

In Manitoba, International Platinum Corporation has several PGE properties. These include the Fox River in the northeastern part of the province and Reed



Exploration in the Ungava region of Quebec (photo courtesy of International Platinum Corporation).

Figure 2

Lake in west-central Manitoba. In Saskatchewan, the Kasner group of companies is involved in several gold-PGE exploration projects in the Beaverlodge area. At Fishhook Bay and Nicholson Bay, the Kasner group has reported exceptional values for gold, platinum and palladium based on preliminary field work. In British Columbia there are several promising areas for PGE exploration including the old Franklin Mining Camp near Grand Forks and in the Tulameen area west of Princeton. Historically, platinum was recovered from gold placer operations on the Similkameen and Tulameen rivers.

In the Yukon, All-North Resources Ltd., (68 per cent owned by Galactic Resources Ltd.), and Chevron Minerals Ltd. are conducting an exploration program at the site of the former Wellgreen nickel mine in the Kluane district, 350 km northwest of Whitehorse. Probable reserves have been calculated at 16.4 Mt grading 0.3 per cent nickel, 0.7 g/t platinum, 0.4 g/t palladium and 0.5 per cent copper. In the Northwest Territories, International Platinum plus Equinox Resources Ltd. in conjunction with Technigen Platinum Corporation, are exploring the Muskox Intrusion in the Coppermine River area. Elsewhere in the Northwest Territories, Asamera Minerals Inc. has undertaken extensive field work on a nickel-platinum-palladium prospect near Rankin Inlet.

Canada appears to have significant potential for platinum metals, but the industry will probably be developed along lines that bear little resemblance to those established within South Africa. Although reserves in the Bushveld Complex are extremely large in comparison with deposits being discovered in Canada, the thinner Bushveld deposits such as the Merensky Reef would be uneconomical in this country. Mining thicknesses, in some cases of less than 1 m, inhibit the mechanization of operations. For this reason and because many Canadian prospects contain relatively high palladium : platinum ratios, only high-grade deposits amenable to low-cost bulk mining methods are expected to be developed in this country.

THE BENEFICIATION OF PGE-BEARING ORES

Canada

As mentioned earlier, the recovery of PGEs contained in the Sudbury nickel-copper ores accounts for the bulk of primary Canadian production. The balance is made up mostly of PGEs recovered from Thompson, Manitoba nickel ores.

The PGEs occur as discrete platinum group minerals (PGMs) within the crystal lattices of certain sulphide minerals such as pentlandite or pyrrhotite, or in arsenide and sulpharsenide minerals such as nickeline (NiAs) and cobaltite (CoAsS). During processing at INCO, the PGEs and much of the PGMs, including any free or partly exposed PGMs, are recovered with the sulphides during sulphide flotation for copper and nickel sulphides and pyrrhotite.

Before 1983 about 70 per cent of the PGEs were recovered in the bulk copper-nickel concentrate from ore assaying 1.4 g/t PGE plus gold. The platinum : palladium : rhodium ratio is about 0.47 : 0.49 : 0.04.

Nickel-copper concentration techniques at Falconbridge's Strathcona and Falconbridge mills are similar to those employed at INCO except that nickel-copper separation of the bulk concentrate is not carried out in the mill.

World

Merensky Reef Ore

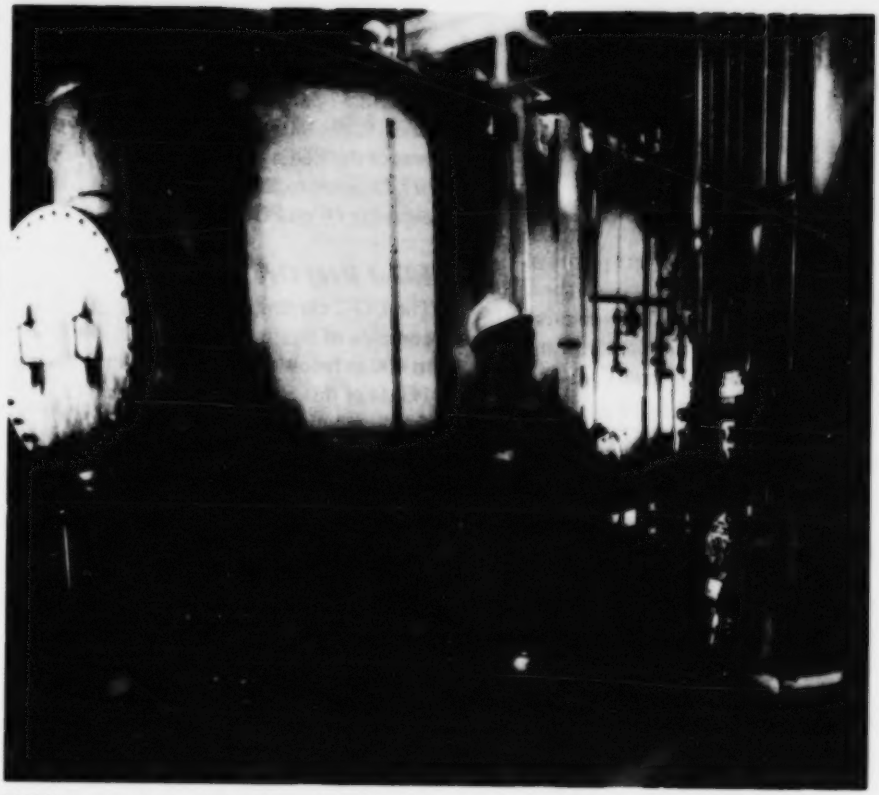
In the Republic of South Africa, a bulk sulphide flotation technique is employed for concentrating the PGMs in the Merensky Reef ore. From a representative mill grade of 7.4 g/t PGEs plus gold (platinum : palladium : rhodium ratio = 0.68 : 0.29 : 0.03), 82 per cent to 85 per cent of the PGEs plus gold are recovered in a flotation nickel-copper concentrate assaying 66 g/t PGEs plus gold.

UG-2 Reef Ore

The UG-2 chromitite layer in the Bushveld complex of South Africa occurs from 30 m to 400 m below the Merensky Reef. The PGMs of this zone are finer grained and the distribution of individual PGEs is somewhat different. The PGMs are predominantly associated with base-metal sulphides or are close by as discrete minerals enclosed by silicates.

The Stillwater Complex in Montana

Ore at the new Stillwater mine in Montana is mineralogically similar to the Merensky Reef of South Africa, but it is of higher grade and has a significantly higher palladium : platinum ratio (3.5 : 1). Concentrate is produced by bulk sulphide flotation and is shipped to Belgium for PGE extraction and refining.



INCO's new precious metals refinery at Port Colborne, Ontario, where platinum group metals are semirefined (photo courtesy of INCO Limited).

EXTRACTION AND REFINING OF PGES FROM PRIMARY SOURCES

Canada

In Canada PGEs are extracted from the Sudbury, Ontario nickel-copper concentrates at the INCO and Falconbridge smelters. At INCO the nickel concentrate is partly roasted and then smelted in a reverberatory furnace to produce a nickel matte containing the PGEs. Further upgrading in converters yields high-grade matte, which is cast into molds and slowly cooled to produce a coarser grain size before treatment in the matte-processing circuit. In this circuit, magnetic separation and flotation are used to produce a magnetic nickel concentrate containing most of the PGEs, and high-grade nickel and copper concentrates. The magnetic concentrate is processed at the Copper Cliff nickel refinery to recover high-purity nickel. Residues from the nickel refinery are pressure leached at the Copper Cliff copper refinery to recover residual copper, nickel and cobalt, and then shipped to INCO's Acton refinery in the United Kingdom to recover PGEs and other constituents.

The copper concentrate from matte separation is processed in the Copper Cliff copper smelter along with the main copper concentrate from INCO's mills. The concentrates are flash smelted to produce a copper matte containing the PGEs and a discard slag. The slimes from electrorefining, containing the PGEs, are shipped to the Acton refinery.

At Falconbridge the bulk nickel-copper concentrate is partly roasted and then smelted in an electric furnace to produce a matte and a discard slag. The matte is further upgraded in converters to produce a high-grade nickel-copper matte containing the PGEs. This matte is shipped to Falconbridge's Kristiansand refinery in Norway, where nickel, copper and cobalt are recovered by a matte leach-purification-electrowin process. Leach residues from this process are further treated to recover PGEs.

At INCO's Thompson plant in Manitoba, PGEs are recovered, along with copper, in the Thompson smelter in the form of a high-grade nickel-copper matte. This is shipped to Sudbury for treatment in the matte processing plant.

Recovery of PGEs in Canadian nickel and copper smelters is greater than 95 per cent.

PGEs are recovered from copper anode slimes at the CCR Division of Noranda Minerals Inc. in Montreal where copper produced at Noranda's Horne smelter is refined. The sources of PGEs are copper and gold concentrates, and metallic scrap processed at the copper smelter. Noranda recently installed a new hydrometallurgical processing system at CCR to separate PGEs from gold and recover them in a bulk precipitate.

World

Most PGE producers outside Canada refine PGEs from PGE-bearing matte, concentrates or anode slimes. South Africa's three refineries produce PGEs primarily from copper-nickel mattes. Two of the producers (Impala Platinum

Some of the many vessels used at a precious metal refinery in Acton, United Kingdom (photo courtesy of INCO Limited).

Holdings Ltd. and Western Platinum Limited) use Sherritt Gordon pressure sulphuric acid leach technology to remove and recover copper, nickel and cobalt before PGE processing. The third producer (Rustenburg Platinum Holdings Limited) uses a modified version of the Sherritt process.

The largest South African refinery is Rustenburg's Wadeville plant at Germiston; it has a capacity of close to 62 t/y. Rustenburg plans to replace this facility in 1989 with a new refinery that will use solvent extraction technology (Solvex process). This process was developed and subsequently used in a large-scale pilot plant at the Royston refinery in the United Kingdom. Matthey Rustenburg Refiners (Pty) Limited owns the plant.

In addition to the South African refineries, there are two refineries in the United Kingdom, two elsewhere in Europe and one in Japan. They produce the rest of the western world's refined PGEs from primary sources. The largest refineries outside South Africa are INCO's Acton refinery and Matthey Rustenburg's Royston refinery, both in the United Kingdom. Capacities are estimated at 11 t/y for Acton and 16 t/y for Royston.

EXTRACTION AND REFINING OF PGES FROM SECONDARY SOURCES

Since 1975 the automotive industry has been a major consumer of platinum and palladium for use in catalytic converters. Up to 6000 kg/a of PGEs are estimated to be recovered in the United States alone from this secondary source. Other secondary sources include electrical-electronic scrap; catalysts from the petrochemical, ceramic and glass industries; and jewelry, dental and medical scrap.

Recovery of PGEs from secondary sources takes place mainly through the smelters and refineries processing the primary sources. Recovery from catalytic converters, however, has resulted in the development of new facilities and processing techniques designed specifically for this secondary source. In the United States four different processes are used by companies that process used auto catalysts. Although some companies are involved only in the removal of PGE-bearing materials, others produce an upgraded material that is ready for final refining.